**JSC/EC5 U.S. Spacesuit Knowledge Capture (KC) Series Synopsis**

**All KC events will be approved for public using NASA Form 1676.**

*This synopsis provides information about the Knowledge Capture event below.*

**Topic** Post-Shuttle EVA Operations on ISS

**Date:** August 26, 2010 **Time:** unknown **Location:** JSC/B5S/R3204

**DAA 1676 Form #: 29696**

A PDF of the presentation is also attached to the DAA 1676 and this is a link to all lecture material and video: \\js-ea-fs-01\pd01\EC\Knowledge-Capture\FY10 Knowledge Capture\20100826_Chullen-West_Post-Shuttle EVA Operations on ISS\For 1676 Review & Public Release

*A copy of the video will be provided to NASA Center for AeroSpace Information (CASI) via the Agency's Large File Transfer (LFT), or by DVD using the USPS when the DAA 1676 review is complete.

**Assessment of Export Control Applicability:**

This Knowledge Capture event has been reviewed by the EC5 Spacesuit Knowledge Capture Manager in collaboration with the author and is assessed to not contain any technical content that is export controlled. It is requested to be publicly released to the JSC Engineering Academy, as well as to CASI for distribution through NTRS or NA&SD (public or non-public) and with video through DVD request or YouTube viewing with download of any presentation material.

* This PDF is also attached to this 1676 and will be used for distribution.

*For 1676 review use_Synopsis_Chullen & West_Post-Shuttle EVA _8-26-2010.pdf*

**Presenters:** Cinda Chullen and William West

**Synopsis**: The EVA hardware used to assemble and maintain the ISS was designed with the assumption that it would be returned to Earth on the Space Shuttle for ground processing, refurbishment, or failure investigation (if necessary). With the retirement of the Space Shuttle, a new concept of operations was developed to enable EVA hardware (EMU, Airlock Systems, EVA tools, and associated support equipment and consumables) to perform ISS EVAs until 2016 and possibly beyond to 2020. Shortly after the decision to retire the Space Shuttle was announced, NASA and the One EVA contractor team jointly initiated the EVA 2010 Project. Challenges were addressed to extend the operating life and certification of EVA hardware, secure the capability to launch EVA hardware safely on alternate launch vehicles, and protect EMU hardware operability on orbit for long durations.

**Biographies:** Cinda Chullen was graduated from Southern Illinois University with a bachelor of science in thermal and environmental engineering. She received her master of business administration and master of science in environmental science from the University of Houston – Clear Lake. In 1985, she joined NASA at JSC as an engineer developing environmental control and life support systems for manned spacecraft in CTSD. In 1990, Chullen became the technical manager of the Science, Engineering, Analysis, and Test (SEAT) Contract, a large high-technology contract providing research and development services

to 18 different technical organizations at JSC. She continued her career in the Engineering Directorate (EA) as the manager of the Business Integration and Operations Office and as the dean of the Engineering Academy. In 2007, she rejoined CTSD in EC5 as the systems lead for the development of the PLSS for an advanced spacesuit. Since joining EC5, Chullen has served as a team lead for Systems Engineering, as a project engineer with the EMU team, as the deputy project manager of the EVA Technology Development Project, and as the team lead in the development of the PLSS Rapid Cycle Amine (RCA) component.

Bill West worked for HS as an ISS EVA increment manager in the EVA Office (XA). He was responsible for Expedition 25 ISS EVA maintenance and served as the XA representative for the Japanese H-II Transfer Vehicle (HTV). Previously, he was the ISS EVA increment manager for Expeditions 4, 6, 10, 15, 19, and 20. West has worked extensively with the Russian EVA community as part of the Joint U.S. and Russian EVA Working Group. He was graduated from Parks College of St. Louis University with a bachelor of science in aerospace engineering and received his master's degree in space science from the University of Houston – Clear Lake. In 1988, he began working at JSC for Rockwell Shuttle Operations Company. In 1997, he joined GHG Corporation and worked in the Safety and Mission Assurance Directorate as a Space Shuttle Main Propulsion System safety engineer and in the EVA Safety Group. Beginning in 2000, West worked for Hamilton Sundstrand.

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# Post-Shuttle EVA Operations on ISS

Bill West
Hamilton Sundstrand Corp

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Cinda Chullen
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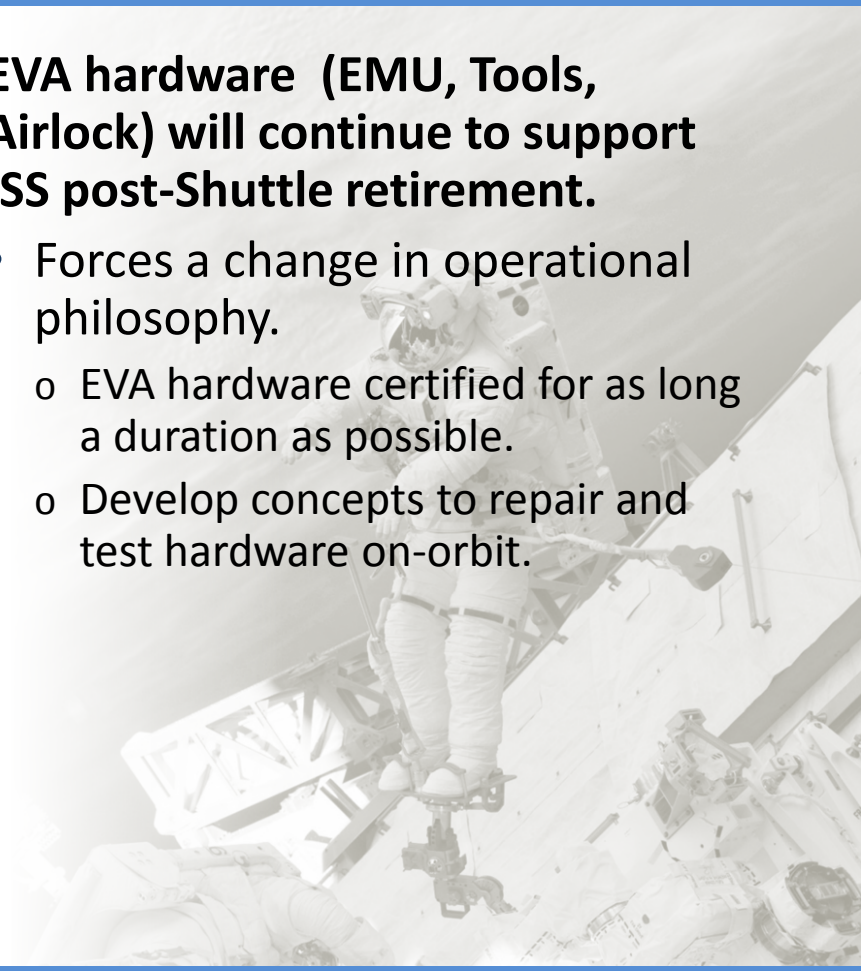
# Challenge of Shuttle Retirement

- **EMU was originally designed in the 1970's/80's for short-duration Shuttle missions.**
  - 1-3 EVAs per Shuttle Mission
  - Refurbished and checked out between Shuttle Flights on ground.
- **Utilized as the U.S. EVA spacesuit for the International Space Station**
  - Certified for 2 years on-orbit or 25 EVAs.
  - Rotated on Shuttle missions for ground refurbishment.
- **EVA hardware (EMU, Tools, Airlock) will continue to support ISS post-Shuttle retirement.**
  - Forces a change in operational philosophy.
    - EVA hardware certified for as long a duration as possible.
    - Develop concepts to repair and test hardware on-orbit.



# EVA Mobility Unit (*the "EMU"*)

Enhanced Arm Assembly

Planner Hard Upper Torso

Helmet/ Extravehicular Visor Assembly

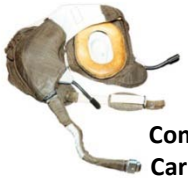
Pivoted Hard Upper Torso

Display and Control Module

Arm Assembly

EMU Electrical Harness

Liquid Cooling and Ventilation Garment



Communications Carrier assembly

Primary Life Support Subsystem

Enhanced Lower Torso Assembly

Insuit Drink Bag

Gloves

Secondary Oxygen Pack

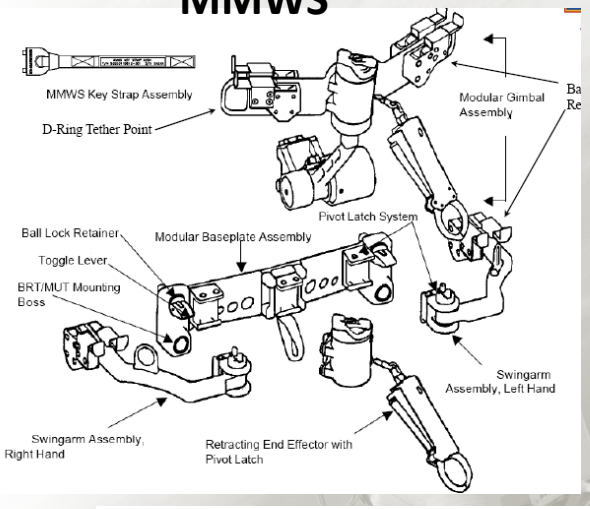
Carbon Dioxide Removal

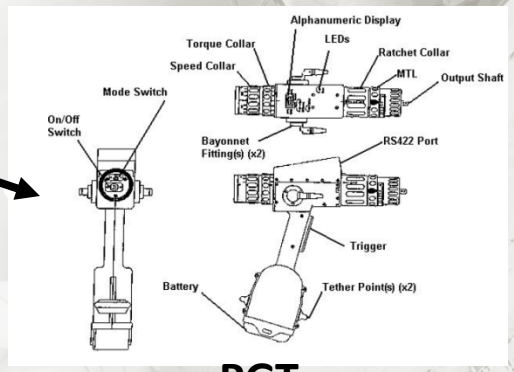
Battery

# EVA Tools


**Safety Tether**

**MMWS**




**PGT**

# USOS Airlock

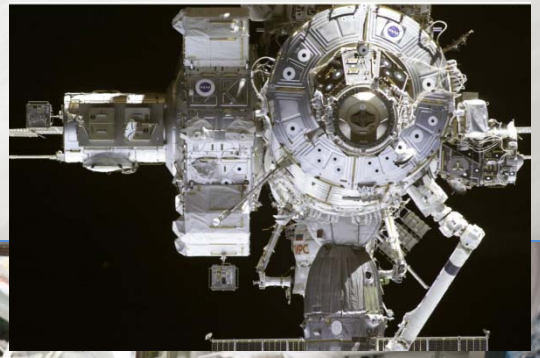
## US Airlock Systems

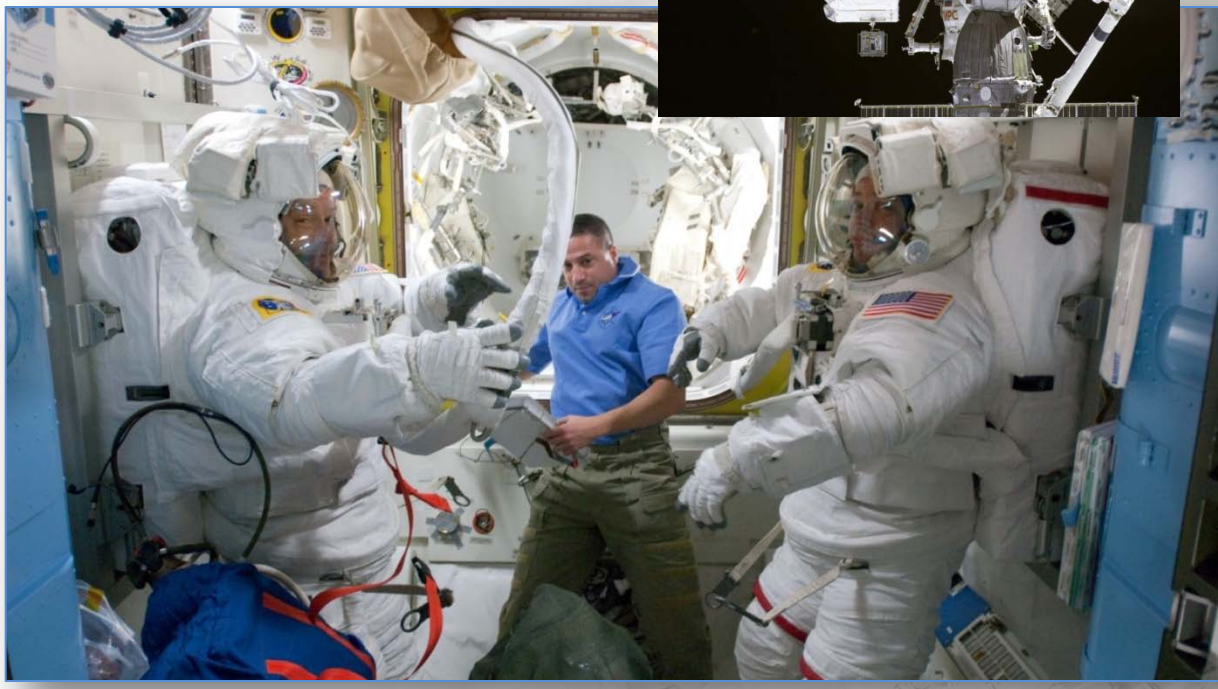
2 modules

- Equipment Lock
- Crew Lock

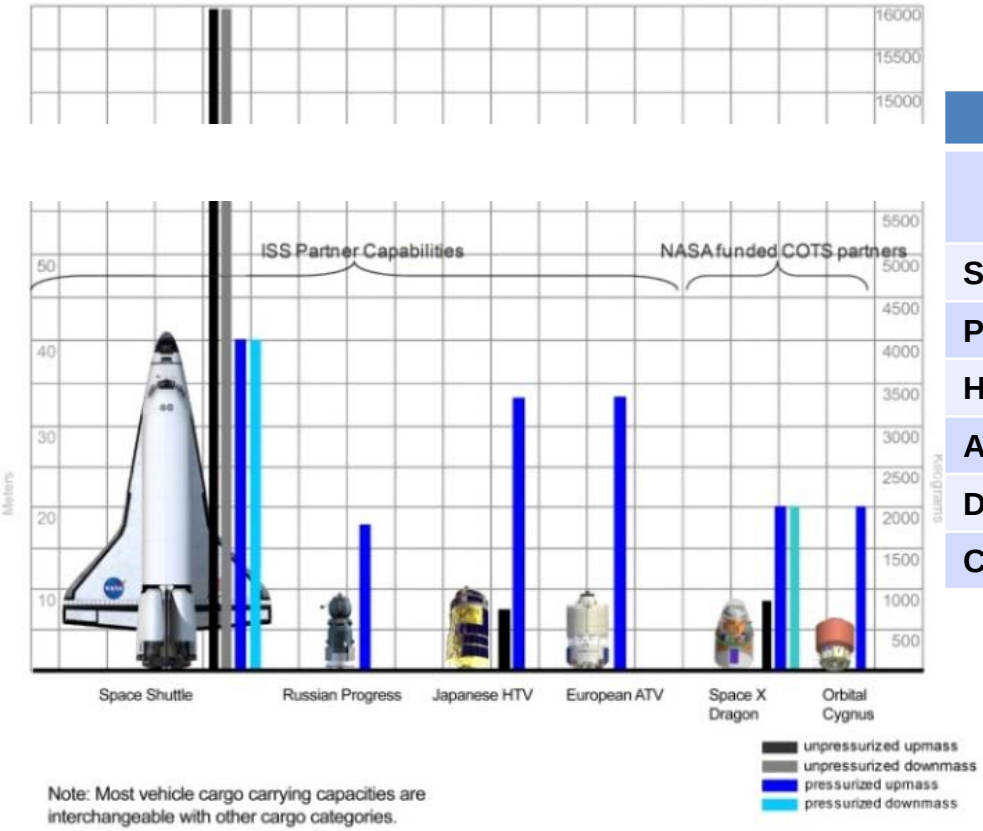
Provides capability to:

- Service & Maintain the EMUs
- Don/Doff Suits
- Store EVA Hardware
- Charge EMU/EVA Batteries
- Provide hardline communications, cooling & power to the EMU
- Egress/Ingress capability to the ISS External Environment





# Average Mission Comparison



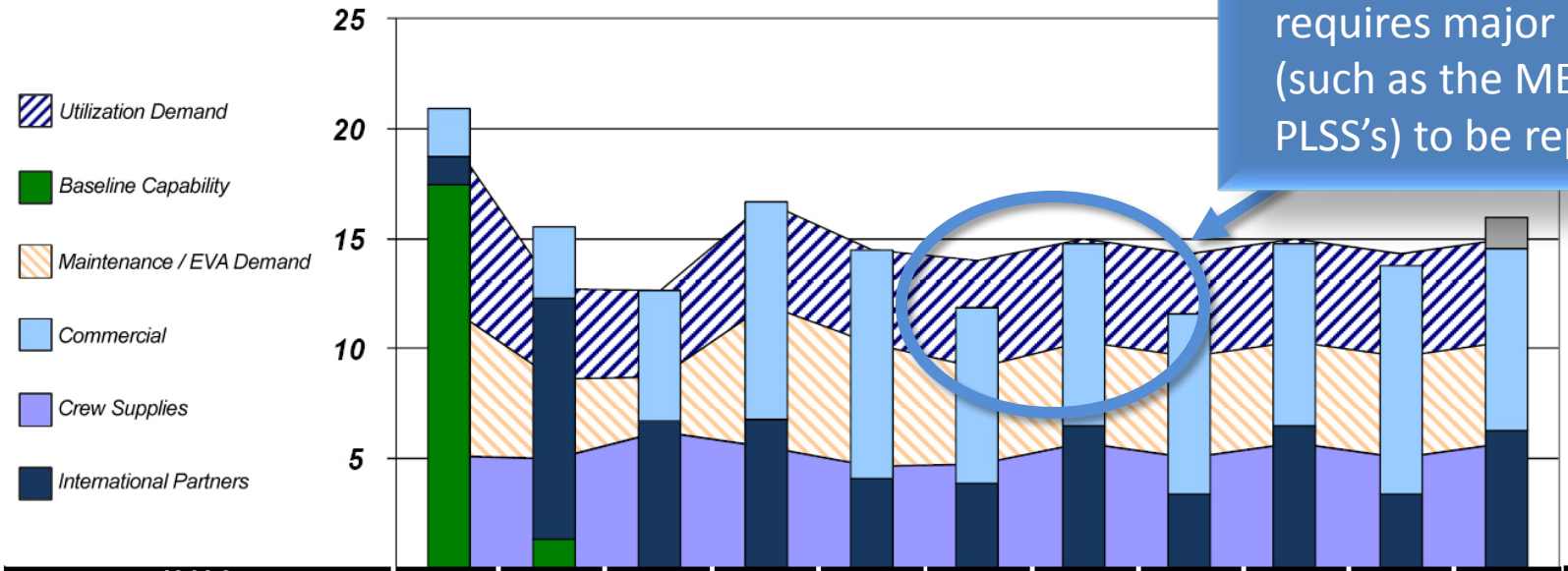

Note: Most vehicle cargo carrying capacities are interchangeable with other cargo categories.

| | Pressurized | | Unpressurized | |
|---|---|---|---|---|
| | **Upmass (kg)** | **Downmass (kg)** | **Upmass (kg)** | **Downmass (kg)** |
| **Shuttle** | **4000** | **4000** | **16000** | **16000** |
| **Progress** | **1800** | **-** | **-** | **-** |
| **HTV** | **2100** | **-** | **700** | **-** |
| **ATV** | **2000** | **-** | **-** | **-** |
| **Dragon** | **2000** | **2000** | **700** | **-** |
| **Cygnus** | **2000** | **-** | **-** | **-** |

*Source: Review of Human Space Flight Plans Committee*

**Critical timeframe for EVA**
– current EVA2010 plan supports to 2015, then requires major EVA h/w (such as the MEGA PLSS's) to be replaced.

## 2010 – 2020 Capability vs. Delivery Demand (MT)




| | Vehicles (CY) | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Baseline | Shuttle | 5 | | | | | | | | | | | 5 |
| | USOS Progress/MRM1* | 4 MT | 1.3 MT | | | | | | | | | | 5.3 MT |
| | USOS Soyuz | 2 | 2 | 2 | 2 | 2 | 2 | | | | | | 12 |
| International Partners | ATV | 1 | 1 | 1 | 1 | | | 1 | | 1 | | 1 | 7 |
| | HTV | | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 11 |
| Commercial | SpaceX | 1 | 2 | 2 | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 28 |
| | Orbital | | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 1 | 14 |

* Value shown in usable cargo (does not include packing, FSE, or accommodations)

*Source: Review of Human Space Flight Plans Committee*

# ISS Ops Post-Shuttle

## Assumptions

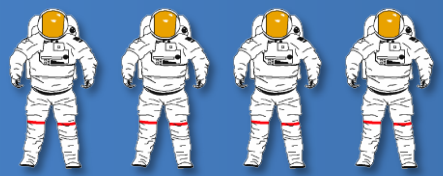
- Continue using EMU for ISS EVA post-Shuttle retirement.
  - Assume hardware is disposable and will not be returned
  - Assume 8 increment EVAs per year with EMU
    - Supports both scheduled & contingency EVAs.

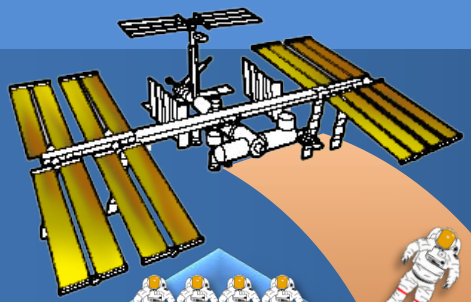
- **EVA hardware (EMU, tools) will be launched on the Japanese HTV**
  - Other IP vehicles (ATV, Progress, & Soyuz) may be utilized to launch EVA hardware to ISS.
  - U.S. Commercial vehicles will be utilized once they are operational.
- **EVA hardware Life Extension**
  - Extend EMU to 6 years on-orbit ("MEGA" EMU)
  - Extend certification for EVA Tools
    - Develop plan to calibrate Pistol Grip Tool on-orbit.

# ISS Ops Concept Post-Shuttle

**ISS assembled**

**4 MEGA EMUs aboard for ISS maintenance ~ 8 EVA /yr.**



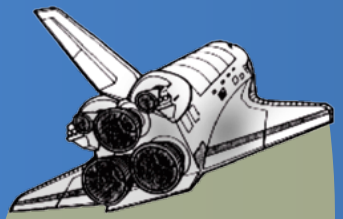


**4 MEGA units replaced over multiple flight as ORUs**

- Replacement EMUs needed to complete assembly on orbit
- Occasional HUT ORU swaps for crew sizing
- SOP replacement may be needed before 2015 & 2020

**2010**

**Shuttle retires**



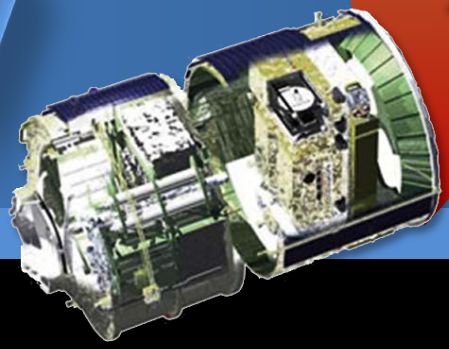
Soyuz provide crew rotations

**2014 -2016**

**Cargo vehicles**

**HTV ~ 13K lbs**

Progress ~4K lbs.



**Disposal in Cargo vehicles**

**2020**

**Present ISS planned use**

# EVA 2010 Project

## EVA 2010 Project

Shortly after the decision to retire the Shuttle was announced, the EVA team kicked off an effort to develop a plan for continued EVA support of ISS in the post-Shuttle environment.

- **Projects Initiated to prepare for ISS ops post-Shuttle**
  - MEGA PLSS
  - EMU 3-6 yr Cert Extension
  - Alt Launch Vehicle
  - Removable Replacement Unit
  - EVA Tool Cert Extension & Calibration
  - Use of ISS Water for the EMU
  - Logistics & Stowage

# EVA 2010 Project: MEGA EMUs

- **Post-Shuttle retirement USOS EVA capability will be performed with EMUs using "MEGA" Portable Life Support Systems (PLSS's)**
- **A MEGA PLSS is a refurbished PLSS that will have all new components and limited life items such that it can support a total of 25 EVAs.**
  - Recoated water tank structure, Aluminum horn, and sublimator face flange
  - All Components lined up to last until 2016 (new builds, refurb)
  - Reset limited life items table to 0 EVAs
- **7-9 MEGAs are planned to support ISS from 2010-2020**
- **Early MEGAs will be delivered and staged on ISS pre-Shuttle retirement**
- **Follow-on MEGA's will be launched on Japanese HTV starting in 2014-2015**
  - Out of life MEGA PLSS's will be discarded when HTV undocks and burns up
  - Some components from the MEGAs may be salvaged prior to being discarded

# EMU 3 to 6 Year Life Extension

- **Current EMU maintenance cycle is 3 years.**
  - Effort in work to extend the EMUs certified maintenance cycle to 6 yrs.
    - 2014-2016 for the first set of Mega EMUs and 2020 for the next set of Mega EMUs.
- **On-orbit diagnostic kit will be utilized to insure EMUs**

# Japanese HTV Cargo Vehicle

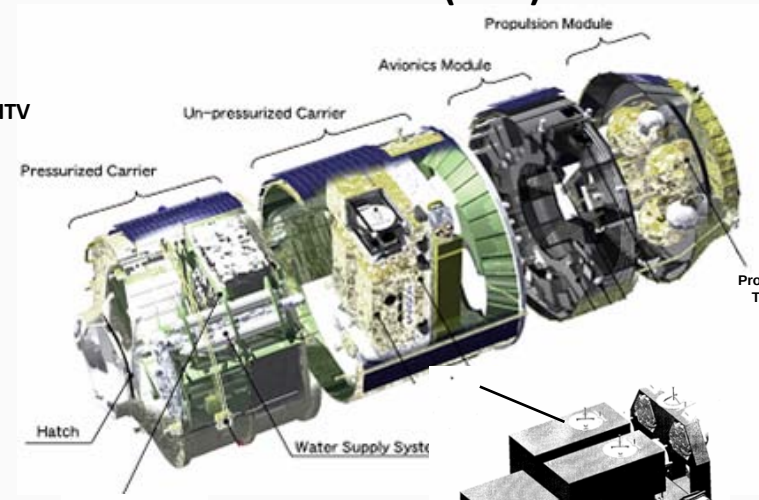
- **H-II Transfer Vehicle (HTV)**
  - Robotic arm captures and berths HTV to ISS
  - Provides atmospheric gas re-supply to the ISS
  - Capable of re-supplying ISS with water
  - Non-removable racks are loaded much like the Shuttle with cargo transfer bags
  - Unpressurized external cargo capability with the HTV external pallet
- **HTV is expendable and offers no recoverable return capability**
  - Non-recoverable cargo and water can be disposed of on re-entry

**HTV Average Capability**

| Cargo Type | Mass (kg) |
|---|---|
| Internal | 2,100 |
| External | 700 |
| Water | 300 |
| N2 | - |
| O2 | - |
| Propellant | - |

**H-IIB Launch Vehicle**


**H-II Transfer Vehicle (HTV)**



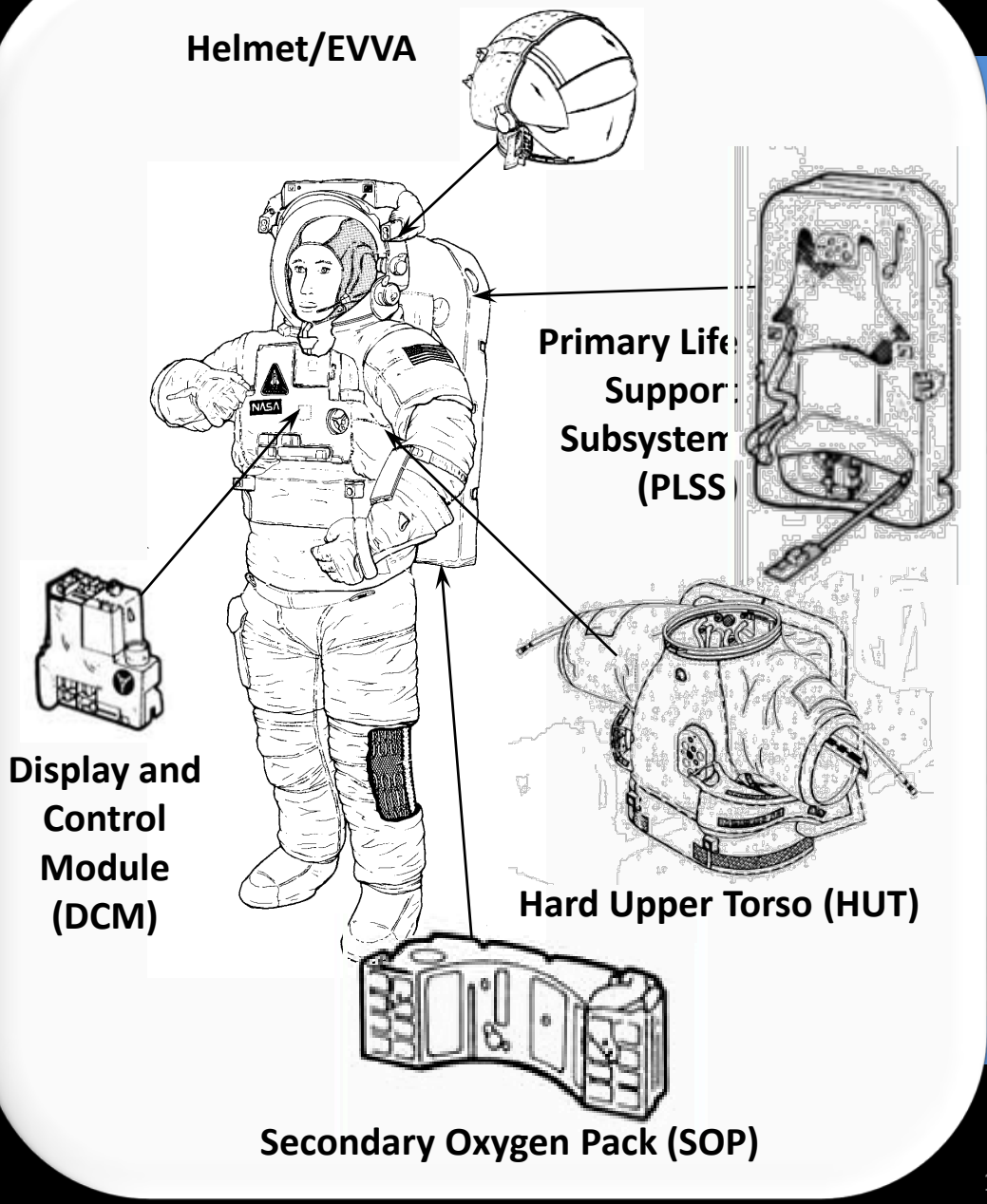

**HTV External Pallet**



**HRR Type 2 HTV Rack**

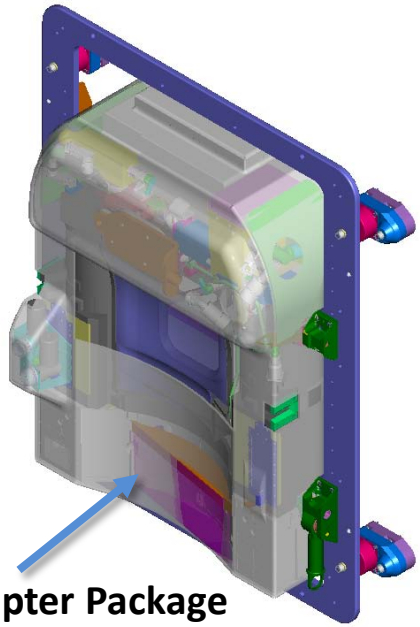
## EMU Hardware on HTV

- **PLSS and or PLSS/SOP launched in a fixture to protect it from vehicle vibrations & launch loads.**
- **DCM, SOP, HUT, etc "soft-stowed" in bags.**
- **Hardware re-assembled & checked out on-orbit.**
  - EMUs are currently launched integrated in Shuttle.



## PLSS/SOP Launch Fixture

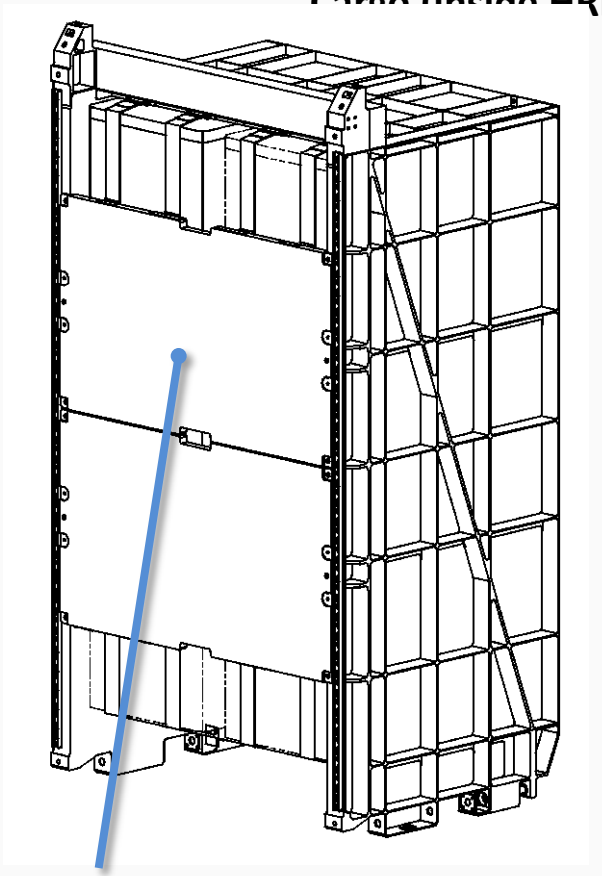
- PLSS launched attached to adapter plate bolted to HTV rack.



Launch Adapter Package

## HTV Resupply Rack (HRR)

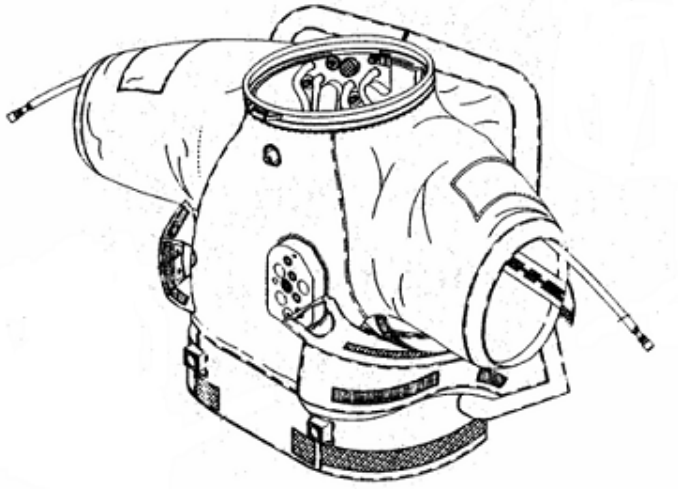
Cargo (inside HRR)



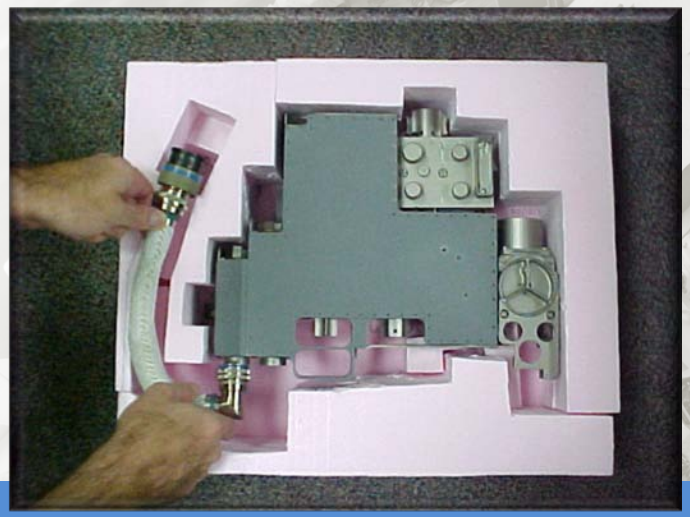
Front Panel

# Example of Soft Stow Items

**HUT set in Foam Box**

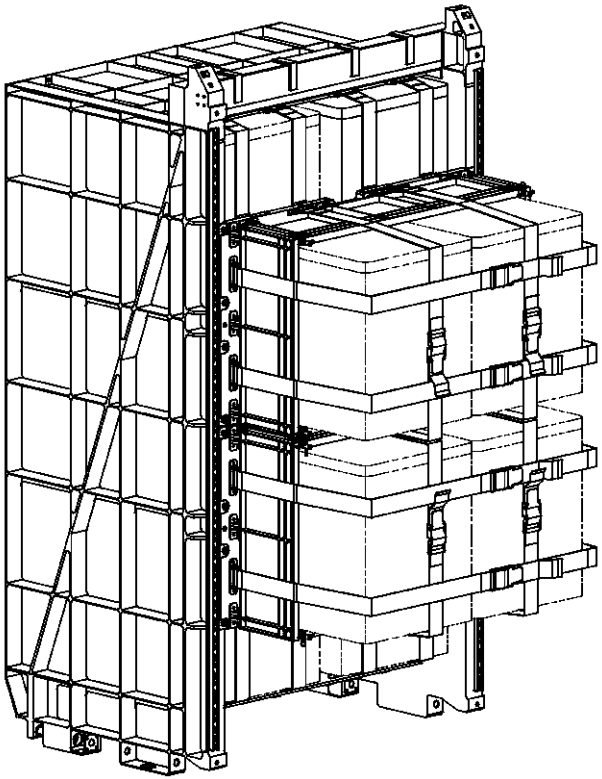


**Hard Upper Torso (HUT)**

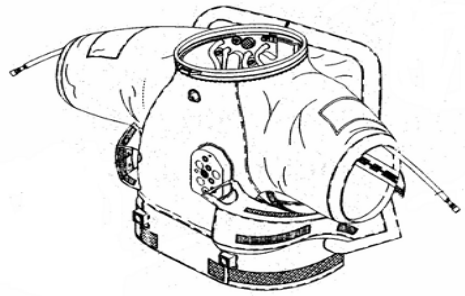


**Display Control Module (DCM)**

# EVA Soft Stow Items: HRR



Cargo (Inside of HRR body)



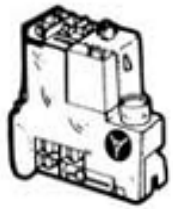
Hard Upper Torso (HUT)

Helmet/E VVA

Cargo

front panel)

Secondary Oxygen Pack (SOP)



Display and Control Module (DCM)

# On-Orbit Troubleshooting & Repair

**Ability of the ISS crew to troubleshoot suit issues and replace suit components is being developed by the EVA team.**

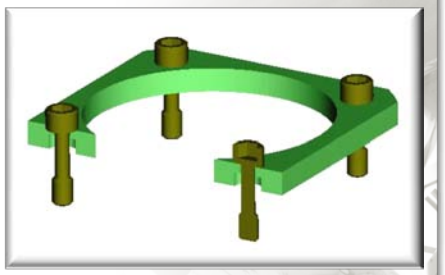
ISS009E19803

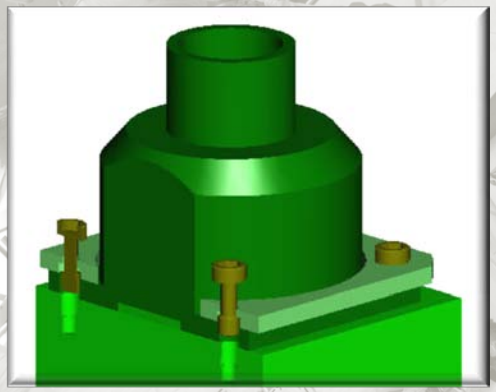
- **Following the Columbia accident, the on-orbit EMUs had several hardware anomalies that deemed them "No-Go" for use.**
  - Replacement h/w was delivered by Russian Progress and crew attempted to recover EMUs.
- **Lessons learned from that effort resulted in the development of RRUs.**

# Repair Replacement Unit (RRU)

- **Components already designed for on orbit maintenance are known as Orbital Replacement Units or "ORUs".**
  - ORU components typically incorporate captive fasteners as part of their design and are certified for removal and replacement.
  - Very few components in the EMU PLSS were designed for on-orbit maintenance.

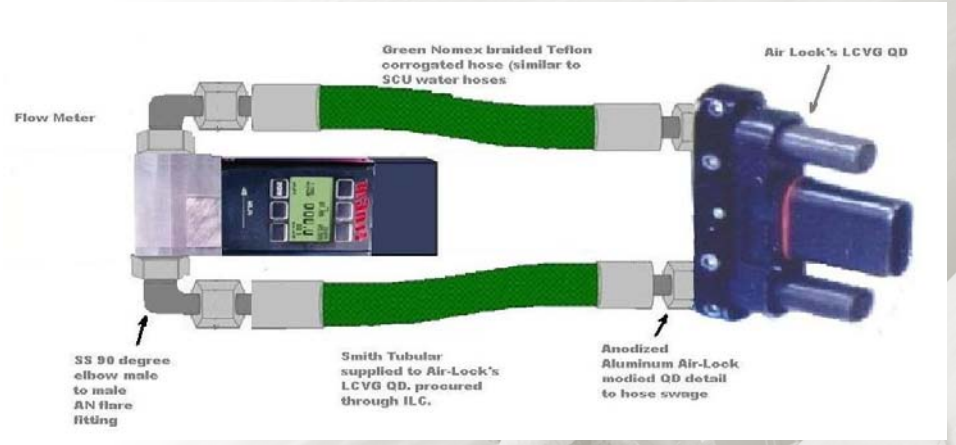
- **RRU is a component that is not already designed for on-orbit removal and replacement.**
  - Custom captive fasteners and yoke plates allow for replacement of small components in the EMU PLSS.





# Diagnostic Tool Kit

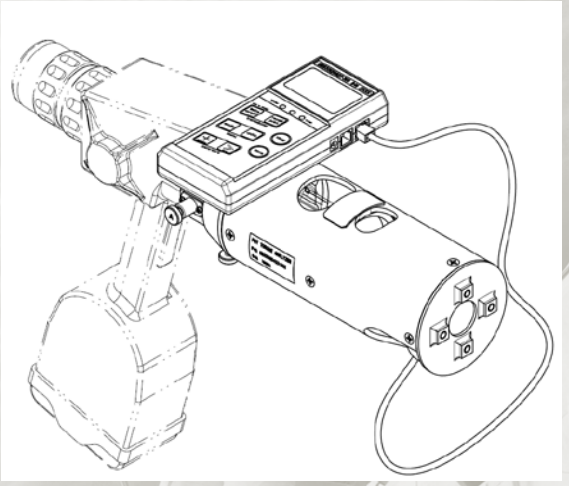
- **Diagnostic Kit is being developed to facilitate the return to service of an EMU after servicing or repair and for monitoring the health of the EMU.**
- **The diagnostic tooling includes:**
  - Hardware to monitor the health of the EMU transport loop flow.
  - Subliminator Flange Leak Detection Strips
  - Vent loop leak detection fixture
  - Cabling to download the software from the EMU Electronic Caution and Warning System (ECWS) and the retrieval of diagnostic and trending data while on ISS.




**EMU Transport Flow Meter**

# EVA Tools: PGT Torque Analyzer Kit

- **Effort underway to extend on-orbit life for EVA Tools.**
- **EVA Pistol Grip Tool (PGT) is a battery-operated, programmable tool used to tighten and loosen various types of nuts, bolts, and other fasteners.**
  - Torque values can be programmed between 0.5-25.5 ft-lb.
  - Current on-orbit life is 2 years then returned to the ground for calibration.
- **On-orbit Torque Analyzer Kit will allow crew to calibration PGT on-orbit.**
  - The objective ofthe PGT TAK is to certify an upgraded torque analyzer system that can be used to verify, with confidence, the accuracy of the PGT torque output such that PGT calibration can be extended to 5 years



# EMU Cooling Loop Feed Water

- **EMU cooling is provided by sublimating water to vacuum.**
  - Water is currently provided from the Shuttle Fuel Cell and stored on-board the ISS for later use with the EMU.
- **Two EMUs use on average 11 pounds of water per EVA**
- **Annually the tanks also need to be drained and filled to iodinate feed water and to expel any gas (9.2 lbs/EMU).**
  - Approximate water usage per year may be around 125 lbs for 4 EMUs/8 EVAS per year.
- **Sublimation can be sensitive to trace amount of contamination on the porous plate.**
  - Negative impact on EMU operations
  - Would require more frequent replacement of the EMU PLSS.
- **ISS EMUs have two options for water supply**
  - Launch water on expendable vehicles (additional upmass requirement to ISS)
  - Use ISS Water Processor Assembly (WPA) water
- **Early test of ground-WPA water identified issue with using WPA water with EMU.**
  - Further testing with samples of ISS produced WPA water inconclusive with ground WPA water.
  - Filter may need to be developed to allow WPA feed water to be used with EMU.

# EVA Logistics & Stowage

- **Shuttle retirement ⇒ Logistical resupply & on-orbit stowage of EVA hardware has to be re-thought.**
  - Goal: sufficient hardware & consumables on orbit to support 8 EVAs per year.
- **Remaining Shuttle flights are pre-positioning EVA hardware to minimize logistical resupply for 2-4 years.**
  - 4 EMUs (1 XL, 2 L, 1 M) + 2 Hard Upper Torsos (HUTs) (XL & L)
    - 3 EMUs & no HUTs have been the baseline through ISS assembly.

# EVA Logistics & Stowage

- **Pantry style approach for EMU hardware that will allow crew-sizing hardware for the maximum number of crewmembers while keeping on-orbit stowage to a minimum.**
- **Sufficient # of EVA tools to support all schedule & unscheduled EVAs with redundancy.**
- **Request to increase EVA hardware on-orbit stowage allocation by 21% made to the ISS Program Office**
  - This is a challenge as many organizations supporting ISS are also requesting an increase in stowage allocation.

# Oxygen Resupply System Challenge

- **ISS Program goal to have full O2/N2 High Pressure Gas Tanks at Shuttle Retirement**
  - Tanks are located externally on the U.S. A/L and provide backup supply of O2 for ISS as well as prime supply of O2 for EVA prebreathe & EMU tanks.

- **N2/O2 Resupply System (NORs) under development to resupply ISS with both high-pressure N2 & O2**
  - Current NORS schedule shows launch of O2/N2 refill capability NET Spring 2013
  - Tanks will be launched by IP or CRS vehicles.

# Oxygen Resupply System Challenge

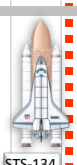
- **Consumables planning shows 13 total Campout Style EVAs available prior to NORS**
  - 13 EVAs in 3 years between Shuttle retirement and NORS on-orbit capability
  - Current ISSP requirement and consumables planning is for 8 EVAs per year
- **Total number of EVA's could be increased, but with shorter overall EVA time with In-Suit Prebreathe Protocol**
  - In-Suit Prebreathe uses 10 lbs O2 vs 25 lbs O2 for Campout protocol
  - Since crew is in the suit an additional 4 hrs during the prebreathe, EVA's are limited to 6:15 hrs due to crew day length

# EVA2010 Integrated Schedule: FY10 – FY11

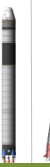
FY10 | FY11 | FY12

Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep | Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep | Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep

**ISS Launch Schedules**











**MEGA Rotation Plan**

EMU 3009

EMU 3010

EMU 3005

4 MEGA SEMUs on-orbit

EMU 3011

**Logistics**

EVA Logistics Plan to support post-2010 EVAs utilizing Shuttle delivery capability

Post-Shuttle Retirement Logistics – IP Vehicle Capability

**6yr Maintenance Certification**

SEMUs certified for 6hr Maintenance Interval

**On-orbit R&R Capability**

Development of PLSS Repair Replacement Unit & Diagnostic capability

On-orbit R&R capability & Diagnostic Kit

**Launching EVA Hardware on HTV**

Development of Alt Launch capability

Capability to launch on IP vehicles (HTV, Progress)

**Post-2010 EMU Water**

WPA Testing & Scrubber Concept Development

Capability to use WPA & IP filled water containers for EMU

**EVA Tool Cert Extensions & New Hardware**

PGT TAK development & manifesting

PGT on-orbit calibration capability

EVA Tool H/W Certification Extension

EVA Tools

# Conclusion

- **Retirement of the Shuttle + continued operation of the ISS until +2020 has forced the EVA community to change its operational philosophy.**
  - Limited resupply capability
  - Hardware becomes disposable
  - On-orbit replacement & testing by crewmembers
- **Opportunity for EVA to prepare for future missions beyond LEO**
  - Long-duration missions to other destinations will mirror this new operational philosophy.